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**Forecasting Research Division**
**Technical Report No. 79**

# Evaluation of the Automated Version of the Moisture Observation Pre-processing System (AutoMOPS)

**by**
**Bruce J. Wright**
**December 1993**

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# Evaluation of the Automated Version of the Moisture Observation Pre-processing System (AutoMOPS)

Bruce J. Wright

6th December 1993

**Abstract**

The Moisture Observation Pre-processing System (MOPS) is an interactive procedure, which is carried out by a forecaster in the Central Forecast Office on a graphics workstation, to produce cloud data for assimilation into the Mesoscale Model. It uses satellite and radar imagery, surface observations, a short model forecast and the application of model-based and empirical rules to generate a three-dimensional cloud analysis. An automated version of the MOPS (AutoMOPS) has been developed to replace the current interactive version, and for implementation within Nimrod. Its introduction would save 95 minutes per day of forecaster time. It includes an improvement to the algorithm for satellite cloud detection and a new method for cloud top height assignment. The AutoMOPS is compared with the operational system for four forecasts which have typical levels of forecaster intervention. Subjective and objective assessment demonstrates that AutoMOPS provides a slight improvement to forecast quality for these cases. Consideration of these and other cases suggests that AutoMOPS is not prone to gross errors. This report describes the new methods used in the AutoMOPS, and the evaluation of the system[1].

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[1] AutoMOPS was introduced operationally on 5th October 1993

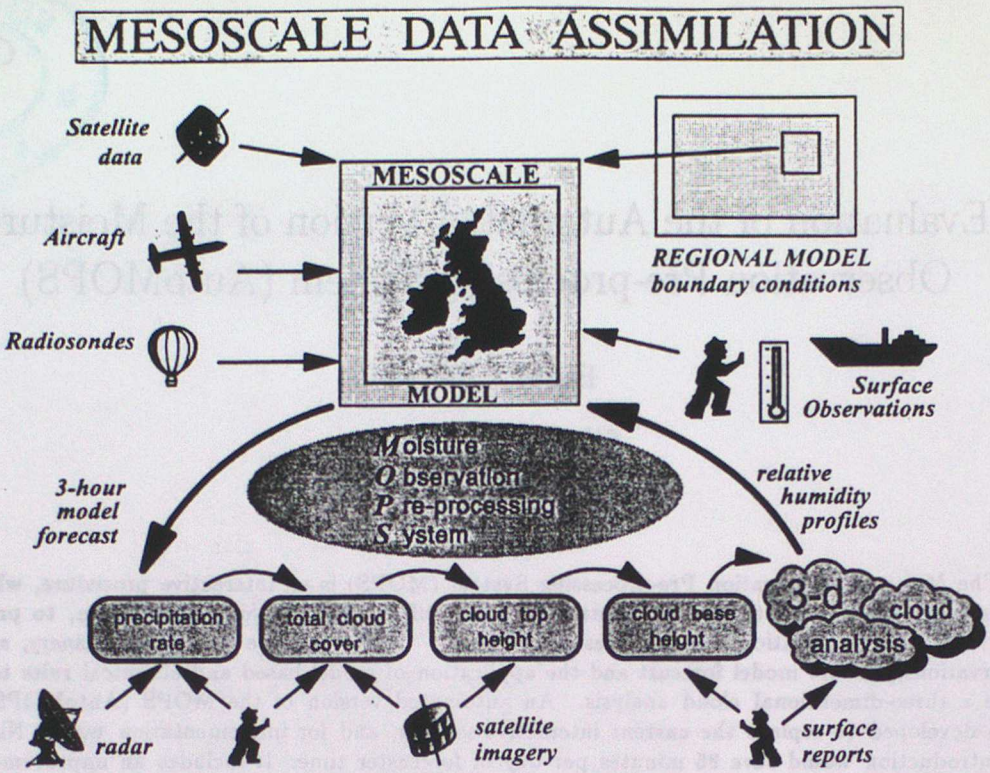



Figure 1: The Assimilation scheme for the Mesoscale Model.

# 1 Introduction

The Moisture Observation Pre-processing System (MOPS) [11] uses satellite and radar imagery, surface observations and a short forecast from the Mesoscale Model [1] to generate a three-dimensional analysis of cloud. This is realised through a sequence of two-dimensional analyses of cloud and precipitation variables. The application of model-based and empirical rules is used to extend the analyses, and the data, to three dimensions. The cloud data is converted to profiles of relative humidity, using the Model cloud scheme relationships [10], before these are assimilated into the Mesoscale Model using the Analysis Correction (AC) data assimilation scheme [7]. A schematic of the Mesoscale Model data assimilation scheme including the MOPS is shown in figure 1.

The MOPS is run on the Front-end computer (HDS) 4 times per day to generate cloud data for the two runs of the Mesoscale Model (data times 00 UTC and 06 UTC). The procedure is run on an interactive graphics workstation as a menu-driven application by the G2 (General Aviation) forecaster in the Central Forecast Office (CFO). This requires approximately 95 minutes of forecaster time per day. It is not always possible for the forecaster to perform the MOPS analysis due to pressure from other tasks—at present 22% of 06 UTC sessions (and 16% of all MOPS sessions) are not carried out.

An automated version of the MOPS, AutoMOPS, has been developed. This requires no forecaster intervention. It includes an improved temperature threshold for the detection of satellite cloud and a new method of cloud top height assignment. The improved cloud detection was tuned using two stratocumulus cloud cases. The new method of cloud top height assignment was developed and tested by Will Hand of the Nowcasting Development Group [6]. The development and use of the improved algorithms within the AutoMOPS are described in section 2

The criteria for operational acceptance of AutoMOPS as specified in the project plan are:

1. The results of case study comparisons should show that, on average, the automated scheme is as good as the interactive one,

2. Significant errors due to the replacement of the interactive with the automated cloud analysis should not occur in more than 1-in-10 forecasts.

The first criterion is addressed by testing the complete system, AutoMOPS, on four cases: two concerned primarily with low cloud, two concerned primarily with rainfall (section 3). Comparison is

made with re-runs of the operational model (version 3.1 of the Unified Model [4]) using the operational (CFO-generated) MOPS data—the use of re-runs reduces the effect of subsequent model changes. Screen temperature, total cloud cover and cloud base height were verified objectively against surface synoptic observations (section 3.1). Subjective verification was carried out for these variables and for precipitation (section 3.2).

The second criterion is addressed by consideration of this study and a separate study, covering a total of eighteen forecasts (section 4).

A summary of the results of the case studies, and conclusions are presented in section 5.

# 2 AutoMOPS

## 2.1 Changes required for the automation MOPS

It is possible to run the interactive version of MOPS in an 'automatic mode'. However, this is not considered safe for operational use. It is necessary to overcome the problems which have made forecaster intervention desirable in the past, before AutoMOPS can be safely introduced. These are: the quality control of imagery and the treatment of missing imagery data; the detection of low cloud from the Meteosat infrared image; cloud top height assignment of low cloud using the Meteosat infrared image. After reviewing the instances of missing or corrupt imagery data, it was decided that there were insufficient cases of either to cause a problem, so no change was made to the current automatic system for selection of imagery data (it selects the required hour, if available). The other two problems are considered to be important, and the solutions which have been adopted are described in the following sections (2.2 and 2.3). A separate change coupled with the testing and introduction of AutoMOPS is the non-use of level 1 MOPS data (see section 2.4)

It is also of interest that automating the procedure renders much of the code, which is approximately 50,000 lines long, obsolete. The removal of all the graphics code, a simplification of the input/output and dataset allocation routines, and the removal of obsolete processing routines reduced the code to about 6000 lines.

## 2.2 Cloud cover detection using infrared Meteosat imagery

The cloud cover scheme interprets pixels as cloudy where the Meteosat infrared image brightness temperature is colder than the model first-guess surface temperature by some threshold temperature. In the MOPS, this temperature difference was quite large, 10 deg $C$, because satellite temperatures were manually calibrated when the scheme was first introduced. However, the imagery is now temperature-calibrated at source, and the 10 deg $C$ threshold can result in a failure to detect warm low cloud over a cold surface (ie anticyclonic stratocumulus cloud).

Inspection of the imagery for the 4/12/91, a stratocumulus case, suggests that the Meteosat infrared brightness temperatures for the sea surface are about 4 deg $C$ below reality. The difference is put down to atmospheric transmission effects; this value and possibly even larger values are confirmed in a paper by Schmetz [9]. Tests on the 4/12/91 and 8/3/93 (another stratocumulus case) cases suggest that a 5 deg $C$ threshold temperature is appropriate for cloud detection; this value reflects the 4 deg $C$ atmospheric correction and a 1 deg $C$ *true* threshold temperature. This value has been adopted.

## 2.3 Cloud top height assignment using infrared Meteosat imagery

The cloud top height assignment is achieved by matching the satellite brightness temperature to the model first-guess temperature profile. This is prone to gross error when the cloud top is associated with a sharp inversion, which is poorly represented in the first-guess profile, either because of insufficient vertical resolution or the absence of the associated cloud-deck in the first-guess. These errors persist despite the introduction of some 'biasing' of the the level temperatures (on the cold side) (see Wright [11] for more detail).

A new algorithm for the detection of low cloud has been developed by Hand [6], based on the idealised temperature and humidity profiles up through a stratocumulus cloud deck (see figure 2).

Hand found the scheme to be very sensitive to the selection of model reference level (the level from which the temperature and humidity profiles are constructed); too low and surface effects dominate, too high and the there is a danger of missing the cloud. Hand's studies suggested that the smallest error in

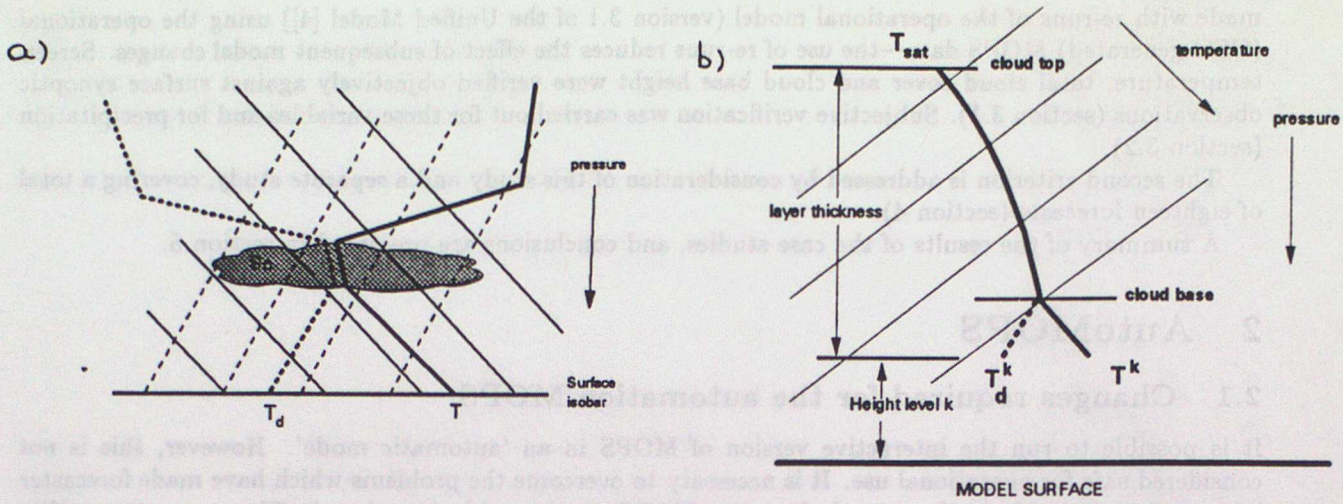



Figure 2: a) Idealized tephigram through a layer of stratocumulus cloud. b) Cloud top height derivation using the new scheme.

cloud top height assignment is achieved using level 3 of the Mesoscale Model ($\approx 180m$) as a reference level. The scheme was developed specifically for low stratiform cloud (eg stratocumulus), but provides sensible results for thick multiple cloud layers, as well.

Within AutoMOPS, the cloud top height is determined from the satellite image on a pixel by pixel basis. A cloud top height is only extracted if the analysed total cloud cover for the corresponding grid-square is greater than 2 oktas. The new scheme is applied to pixels with a brightness temperature above $-20 \deg C$. For other pixels the original scheme is used. If the pixel temperature is warmer than the reference temperature, then, once again, the original scheme is used.

Tests were carried out for the cloud top height assignment within the AutoMOPS on the 4/12/91 and 7/3/93 (both stratocumulus cases). Comparisons were made between the original scheme, the new scheme and the composite scheme. Significant improvements in cloud top heights were observed when using the new (and the composite scheme), rather than the old scheme. For high cloud, differences were less pronounced, but use of the original scheme (and the composite), appeared to give more realistic heights than the new scheme. It was concluded that this combination of the two cloud top height assignments methods produced good (and safe) results when used within the AutoMOPS.

### 2.4 Non-use of level 1 MOPS data

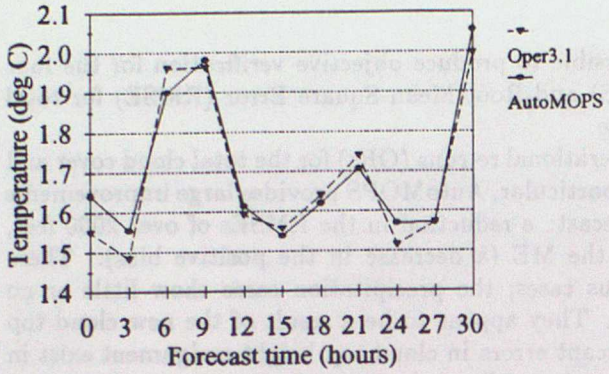
MOPS is designed to use as many of the available cloud cloud observations as possible. However, it does not use the surface synoptic visibility reports or Present Weather fog reports. Cloud is only inserted at the lowest levels if 'sky obscured' is reported (see Wright [11] for details). Thus, there is the risk of removing or inhibiting the growth of shallow fog by forcing the model to be cloud-free at level 1. The non-use of the level 1 MOPS data becomes even more desirable with the introduction of screen-level humidity (dew point temperature) data into the assimilation. Although not included in the case studies, screen level humidity data was introduced operationally 14th September 1993. For these reasons the AutoMOPS data has not been used at level 1 in the case studies. This means no humidity data is assimilated at level 1 for the AutoMOPS forecasts in the case studies.

## 3 Cases Studies

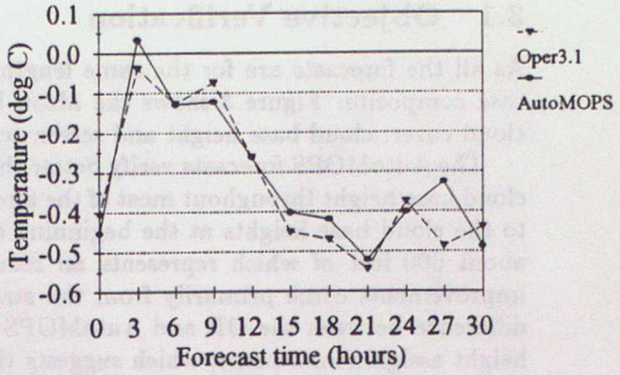
The AutoMOPS has been run on four cases, two where the principle interest was low cloud (06 UTC 7/3/93 and 06 UTC 8/3/93) and two where the principle interest was precipitation (06 UTC 12/4/93 and 06 UTC 14/6/93); all were 30 hour forecasts. Ballard and Macpherson [2] describe the performance of the models in the forecasting of stratocumulus in the period from 5–10/3/93, a period which includes the two low cloud cases studied here.

The cases represent a a range of levels of intervention typical of CFO. The AutoMOPS forecasts are compared with re-runs using the operational MOPS cloud data, but with the current version of the

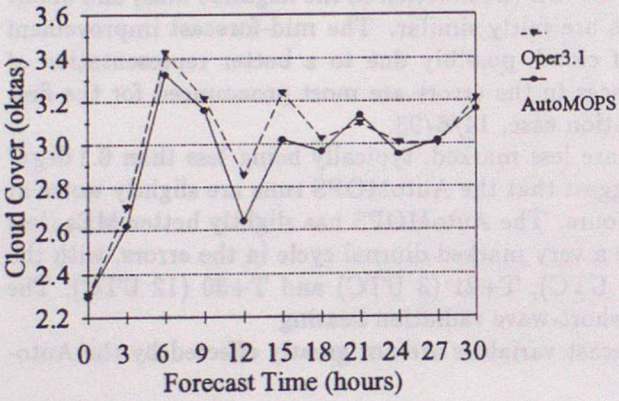
a) Screen Temperature RMS Errors



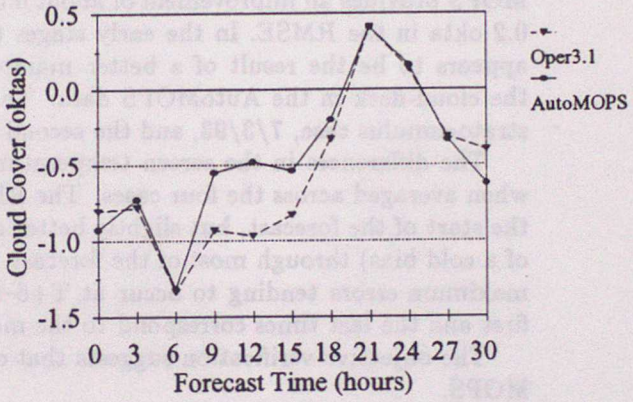

b) Screen Temperature Mean Errors



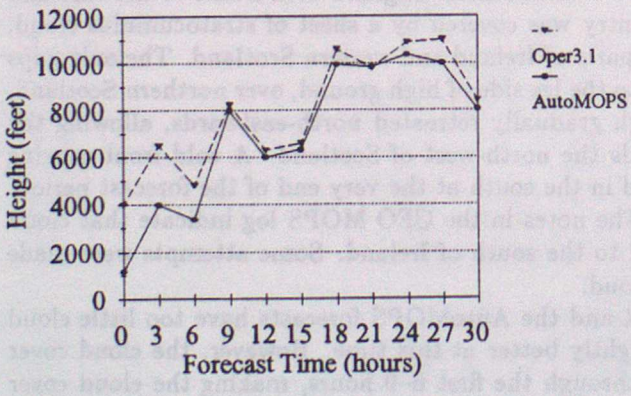

c) Total Cloud Cover RMS Errors




d) Total Cloud Cover Mean Errors




e) Cloud Base Height RMS Error




f) Cloud Base Height Mean Error

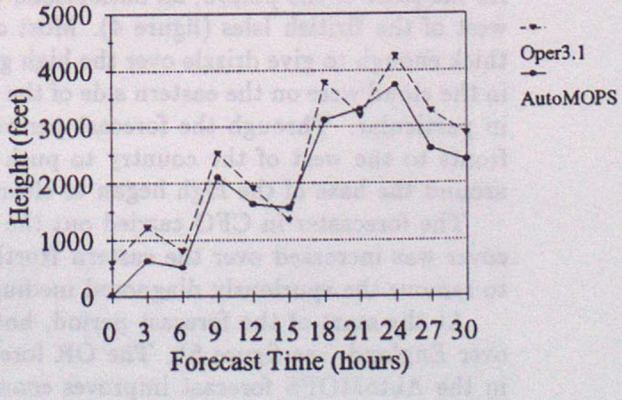



Figure 3: Mean and Root Mean Square errors for: a) & b) screen temperature, c) & d) cloud base height, e) & f) total cloud cover.

Unified Model (version 3.1). This is to reduce the effect of any model changes which have occurred since the operational MOPS data was generated. Cloud, precipitation and screen temperature are assessed subjectively. Objective verification of cloud and temperature is assessed.

## 3.1 Objective Verification

As all the forecasts are for the same length, it is possible to produce objective verification for the four case composite. Figure 3 shows the Mean Error (ME) and Root Mean Square Error (RMSE) for total cloud cover, cloud base height and screen temperature.

The AutoMOPS forecasts verify better than the operational re-runs (ORs) for the total cloud cover and cloud base height throughout most of the forecast. In particular, AutoMOPS provides large improvements to the cloud base heights at the beginning of the forecast: a reduction in the RMSEs of over 2000 feet, about 600 feet of which represents an reduction in the ME (a decrease in the positive bias). These improvements come primarily from the stratocumulus cases; the precipitation cases show little or no difference between the OR and AutoMOPS forecasts. They appear to be a result of the new cloud top height assignment scheme, which suggests that significant errors in cloud top height assignment exist in the operational MOPS Analysis despite human intervention. There are also differences in the cloud base errors in the last 12 hours of the forecast, the AutoMOPS forecast being better. These are mainly the result of an improvement in the second precipitation case, 14/6/93.

The differences in the total cloud cover errors are most evident between T+6 and T+18 hours. AutoMOPS provides an improvement of about 0.5 okta in the ME (a reduction in the negative bias) and about 0.2 okta in the RMSE. In the early stages the errors are fairly similar. The mid-forecast improvement appears to be the result of a better maintenance of cloud, possibly due to a better representation of the cloud-deck in the AutoMOPS data. The differences in the errors are most pronounced for the first stratocumulus case, 7/3/93, and the second precipitation case, 14/6/93.

The differences in the screen temperature errors are less marked, typically being less than 0.1 deg $C$ when averaged across the four cases. The RMSEs suggest that the AutoMOPS runs are slightly worse at the start of the forecast, but slightly better at T+6 hours. The AutoMOPS has slightly better MEs (less of a cold bias) through most of the forecast. There is a very marked diurnal cycle in the errors, with the maximum errors tending to occur at T+6–9 (12–15 UTC), T+21 (3 UTC) and T+30 (12 UTC). The first and the last times correspond to the maximum short-wave radiation heating.

The objective verification suggests that other forecast variables are not greatly effected by the AutoMOPS.

## 3.2 Subjective Verification

### 3.2.1 Case 1: 6 UTC 7th March 1993

At the start of the period, an anticyclone was centred over southern England with fronts to the east and west of the British Isles (figure 4). Most of the country was covered by a sheet of stratocumulus cloud, thick enough to give drizzle over the high ground in parts of Ireland and western Scotland. The only gaps in the cloud were on the eastern side of the country, to the lee side of high ground, over northern Scotland, in particular. Through the forecast period, the high gradually retreated north-eastwards, allowing the fronts to the west of the country to push in towards the north-west of Scotland. A cold front moving around the base of the high began to clear the cloud in the south at the very end of the forecast period.

The forecaster in CFO carried out the MOPS. The notes in the CFO MOPS log indicate that cloud cover was increased over the eastern North Sea and to the south of Ireland. Some attempts were made to remove the spuriously diagnosed medium-level cloud.

At the start of the forecast period, both the OR and the AutoMOPS forecasts have too little cloud over England (see figure 5). The OR forecast is slightly better at this time. However, the cloud cover in the AutoMOPS forecast improves considerably through the first 6–9 hours, making the cloud cover predictions of the AutoMOPS at T+6 (12 UTC) and beyond superior to the OR forecast (figure 6).

The OR forecast generates spurious medium-level cloud over Ireland and western England at T+6 (figure 6), which persists well in to the forecast (figure 7), not dissipating until about T+12. The AutoMOPS forecast does not produce this cloud. Figure 8 highlights the problem; it shows the forecast and observed temperature and humidity profiles for Cambourne at 12 UTC 7/3/93 (T+6). A moist layer at 750 mb can be seen clearly in the OR forecast profile (figure 8b). In comparison, both the observed and the AutoMOPS forecast profiles (figures 8a and c) are dry at this level. This erroneous moist layer

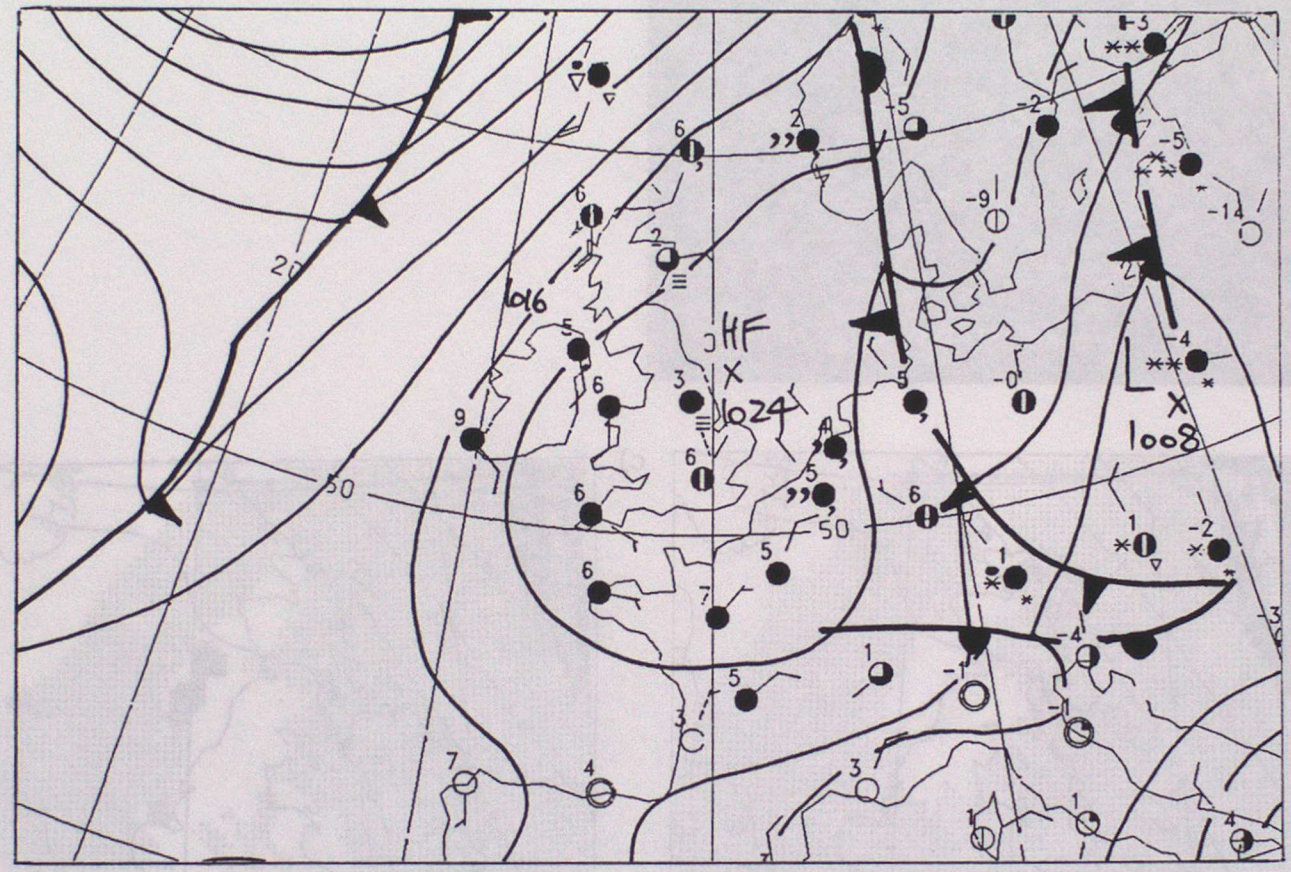
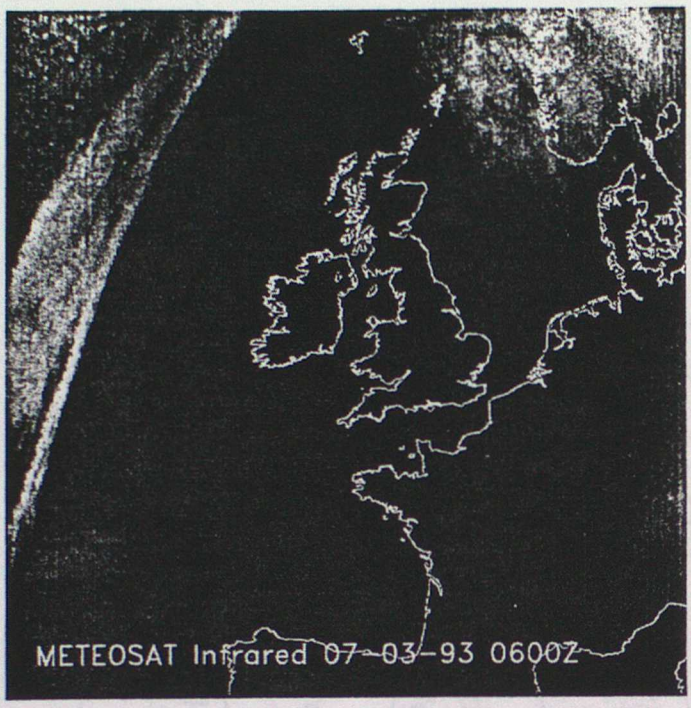



Figure 4: Surface synoptic chart for 6 UTC 7/3/93.

a)

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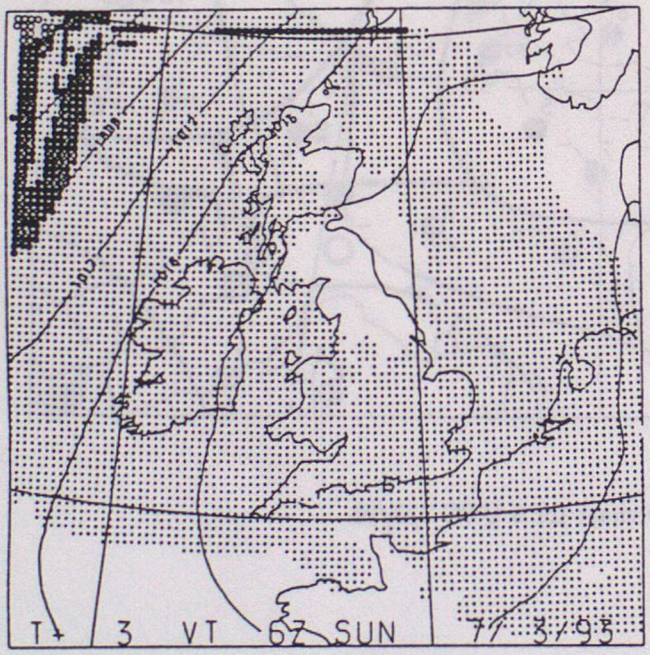



c)

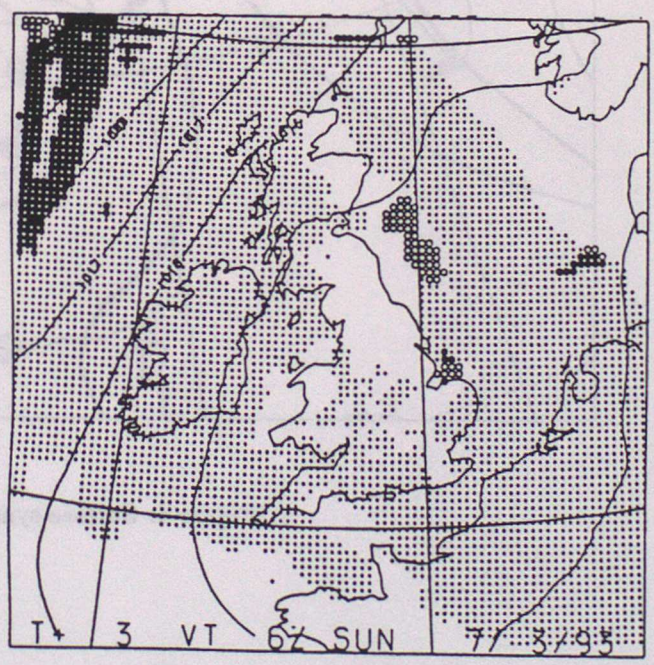



Figure 5: Satellite imagery and model forecasts valid at 6 UTC 7/3/93 a) Meteosat infrared image, b) Operational re-run T+0 forecast, c) AutoMOPS T+0 forecast.

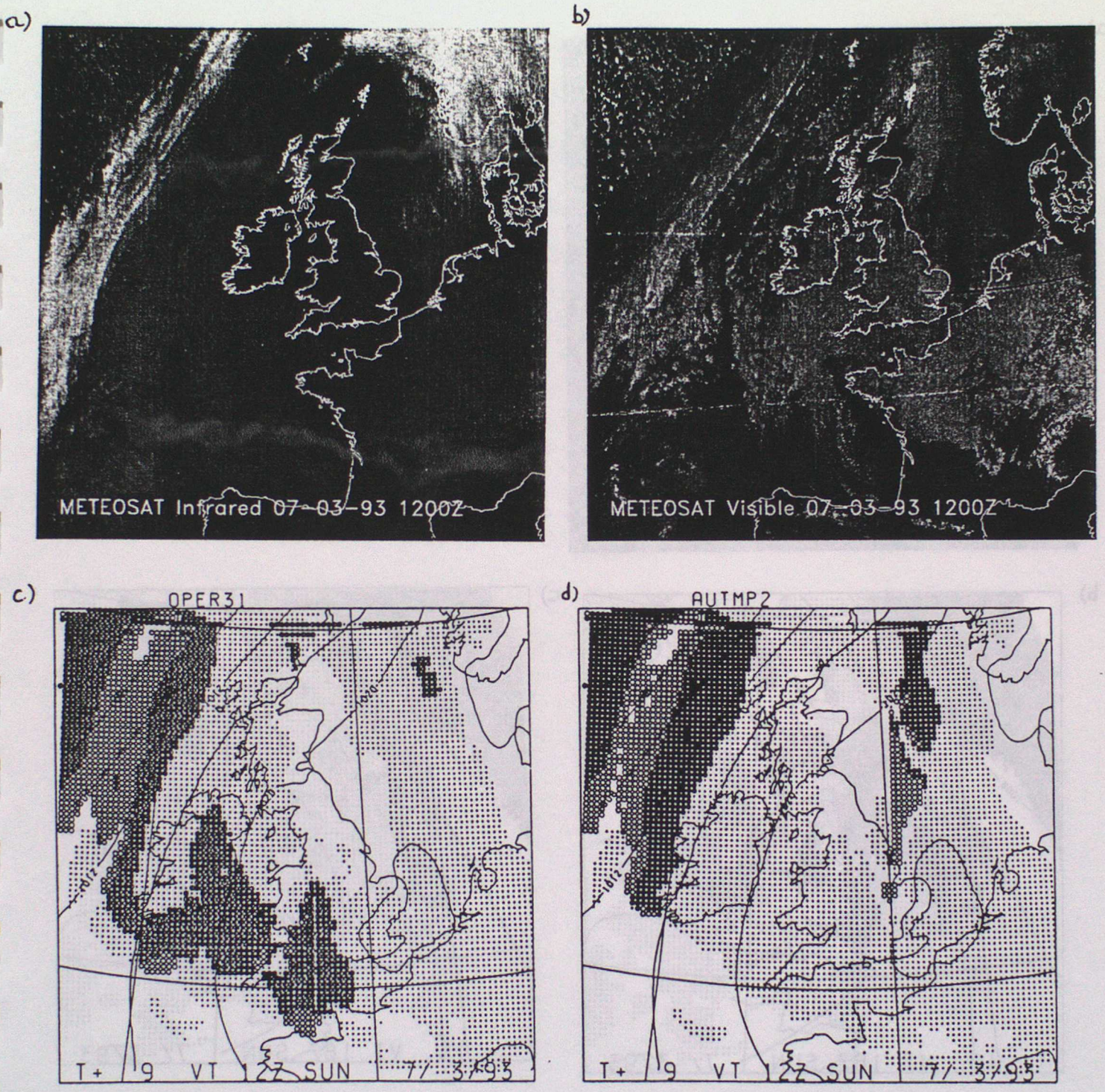



Figure 6: Satellite imagery and model forecasts valid at 12 UTC 7/3/93 a) Meteosat infrared image, b) Meteosat visible image, c) Operational re-run T+6 forecast, d) AutoMOPS T+6 forecast.

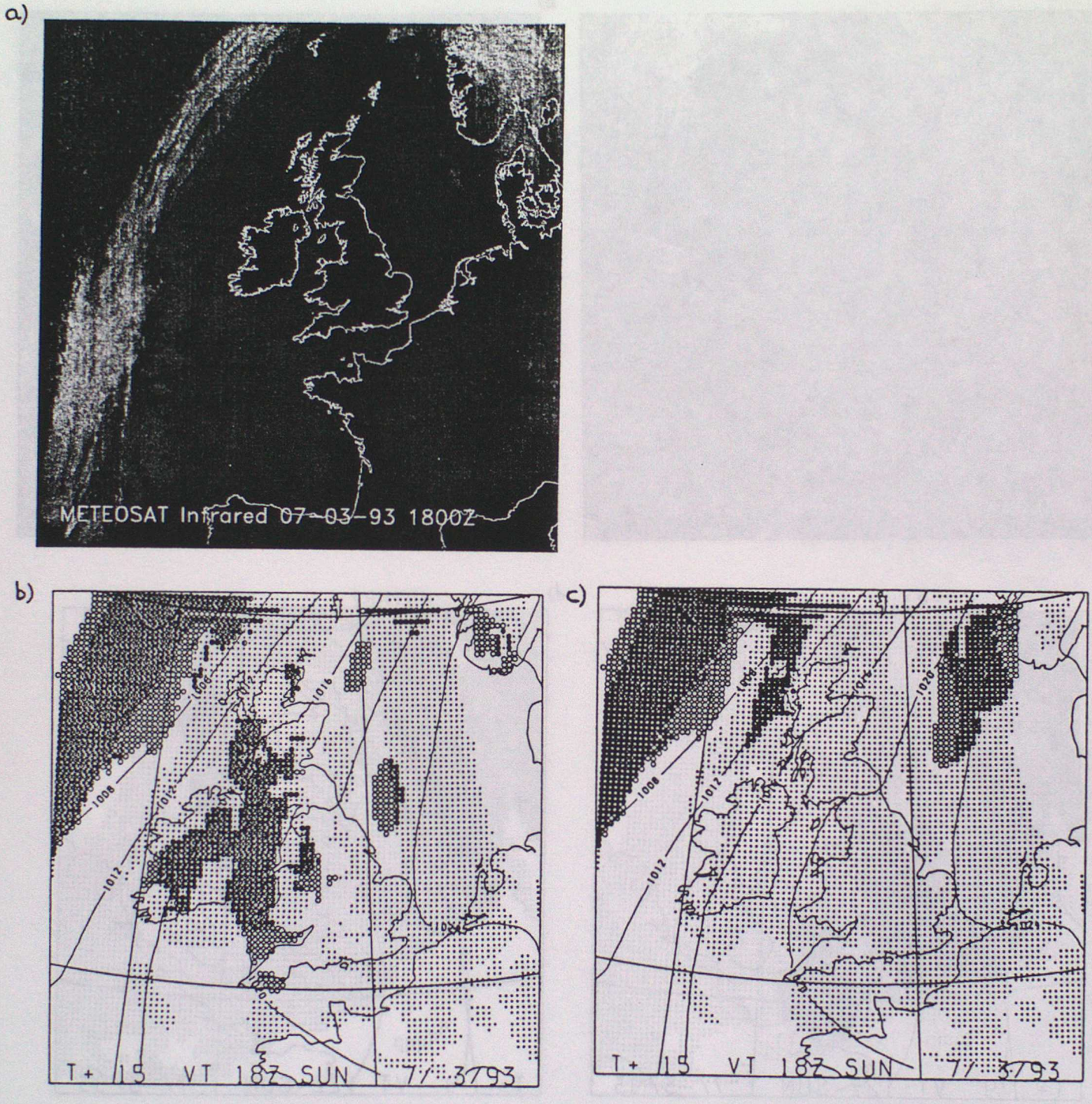



Figure 7: Satellite imagery and model forecasts valid at 18 UTC 7/3/93 a) Meteosat infrared image, b) Operational re-run T+12 forecast, c) AutoMOPS T+12 forecast.

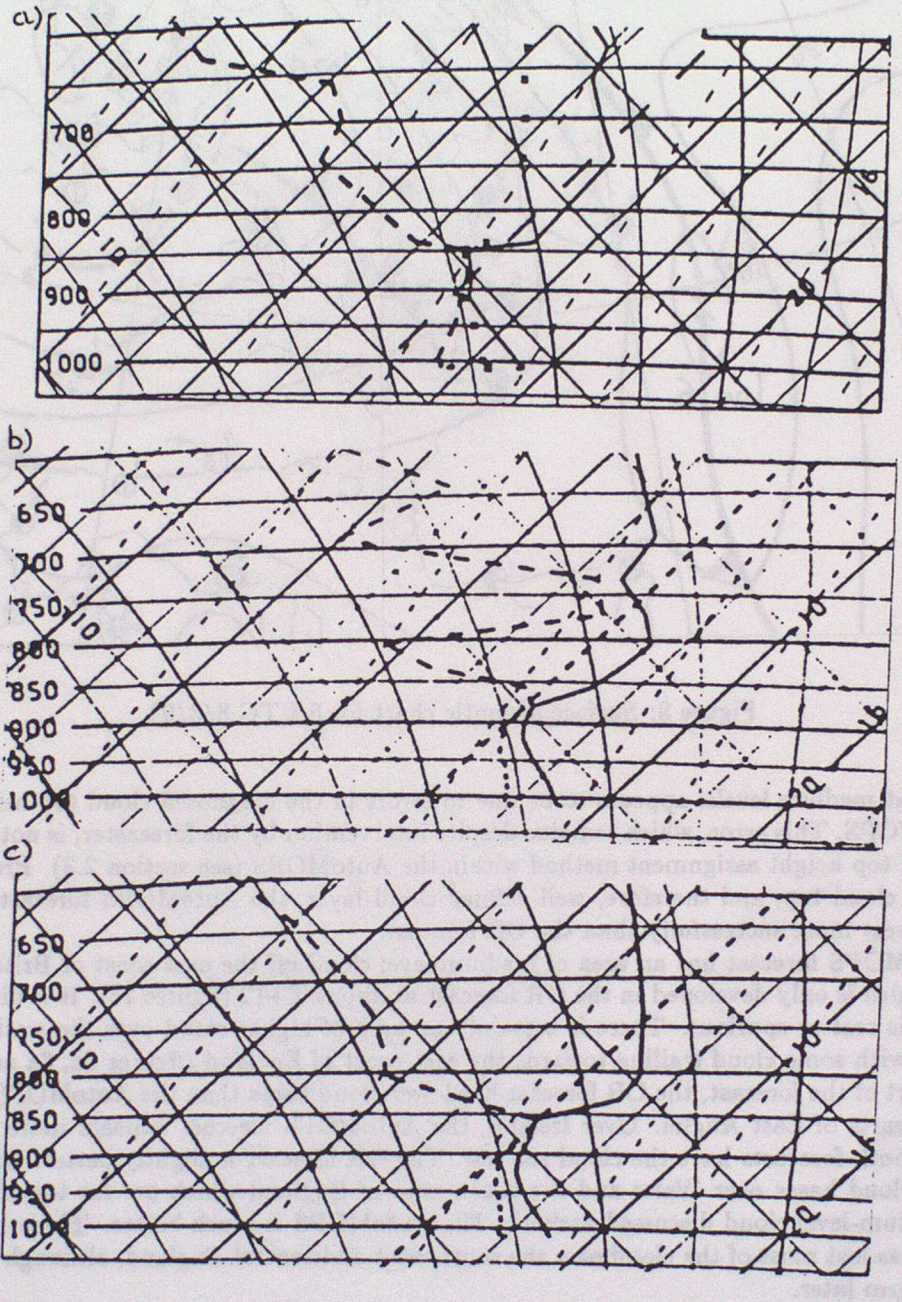



Figure 8: Temperature and humidity profiles for Cambourne valid at 12 UTC 7/3/93 a) Actual radiosonde ascent, b) Operational re-run T+6 forecast, c) AutoMOPS T+6 forecast.

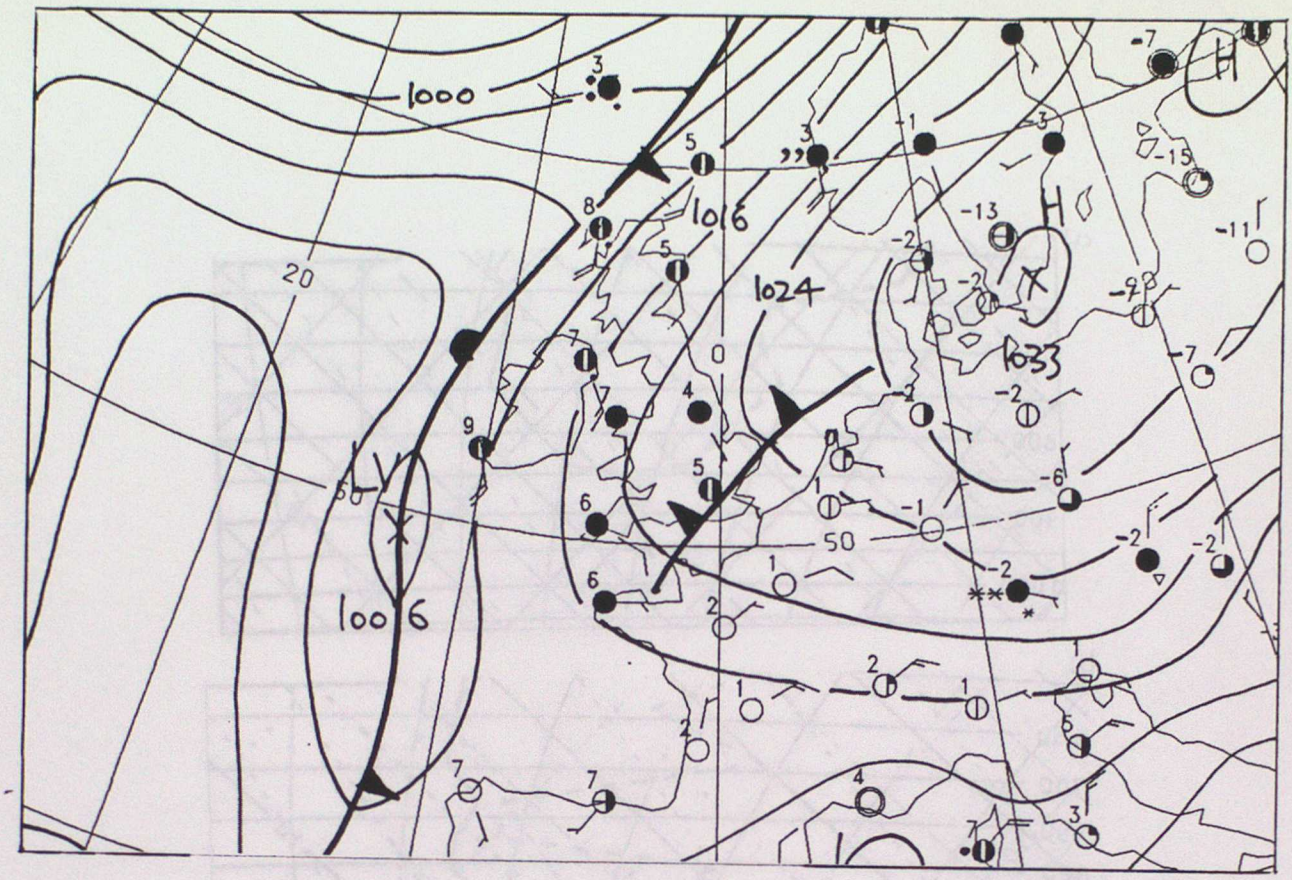



Figure 9: Surface synoptic chart for 6 UTC 8/3/93.

(cloud-deck) at medium levels, appears to be due to errors in the diagnosed cloud top height within the operational MOPS. This error, which remains despite intervention by the forecaster, is not reproduced by the new cloud top height assignment method within the AutoMOPS (see section 2.3). Probably because of this better cloud top, and therefore, well-defined cloud layer, the AutoMOPS forecast maintains the cloud in the west more successfully than the OR forecast.

The AutoMOPS forecast has an area of medium-level cloud off the east coast of Britain (figures 5b, 6c and 7b) which is only developed in the OR forecast at about T+12 (figures 7c). It is difficult to assess whether this is real or spurious. There is certainly an area of higher cloud over the western North Sea and Norway, with some cloud trailing towards the east coast of England (figures 5a, 6a and 7a).

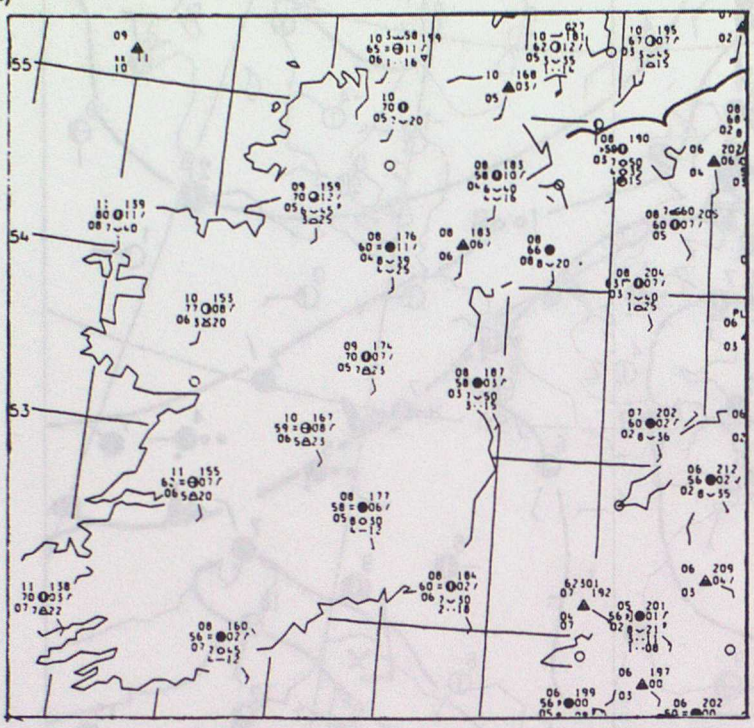
At the start of the forecast, the OR forecast has lower cloud bases than the AutoMOPS over southern Ireland, and parts of East Anglia. Over Ireland, the AutoMOPS forecast appears more realistic. Over East Anglia, both forecasts have the cloud too low. The OR forecast is slightly better. At T+9, the OR forecast has cloud bases over Wales and the south-west of England which are far too high (associated with the medium-level cloud discussed earlier). The AutoMOPS is much better. Three hours later, the OR forecast has lost most of the cloud over the south-west and central England, although low cloud does appear to reform later.

Towards the end of the forecast period, the two runs look fairly similar, although closer inspection reveals some differences in the cloud breaks on the eastern side of Britain and the distribution of the medium-level cloud over the North Sea. Both runs have cloud too low over the North Sea throughout the forecast period.

### 3.2.2 Case 2: 6 UTC 8th March 1993

The synoptic situation for the previous day has been described in section 3.2.1. By 8/3/93, a ridge was still present over the British Isles, but fronts to the north-west of Britain were beginning to make slow progress into northern Scotland (figure 9). A very weak cold front (no precipitation) skirting around the base of high brought a gradual clearance of the low cloud from the south.

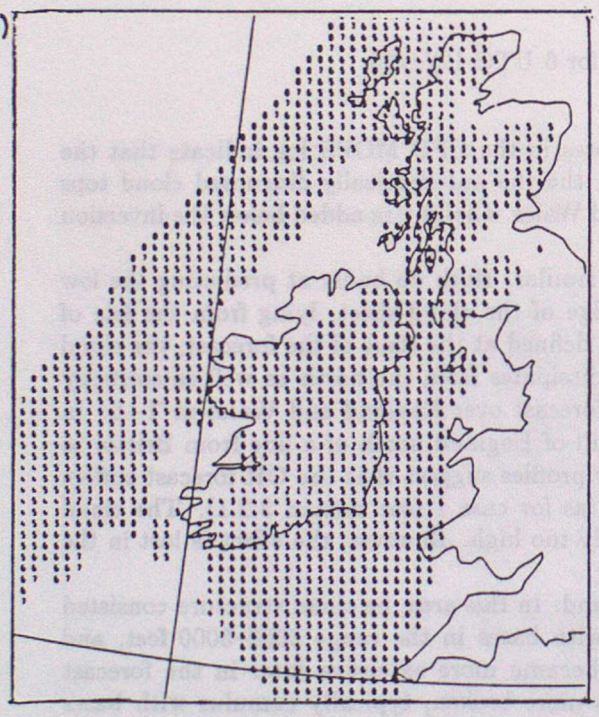
a)




b) Cloud Base Codes

| Code | Range (feet) | | |
|---|---|---|---|
| 0 | 0 | → | 150 |
| 1 | 150 | → | 300 |
| 2 | 300 | → | 600 |
| 3 | 600 | → | 1000 |
| 4 | 1000 | → | 2000 |
| 5 | 2000 | → | 3000 |
| 6 | 3000 | → | 4950 |
| 7 | 4950 | → | 6500 |
| 8 | 6500 | → | 8000 |
| 9 | 8000 | and above | |

c)



d)

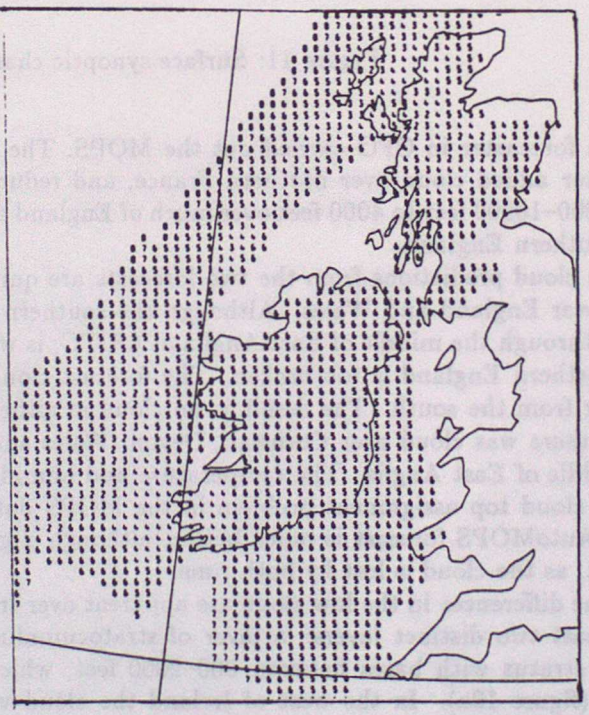


Figure 10: Cloud bases valid at 12 UTC 8/3/93 a) Surface synoptic observations, b) Mesoscale Model cloud base codes, c) Operational re-run T+6 coded cloud base forecast, d) AutoMOPS T+6 coded cloud base forecast.

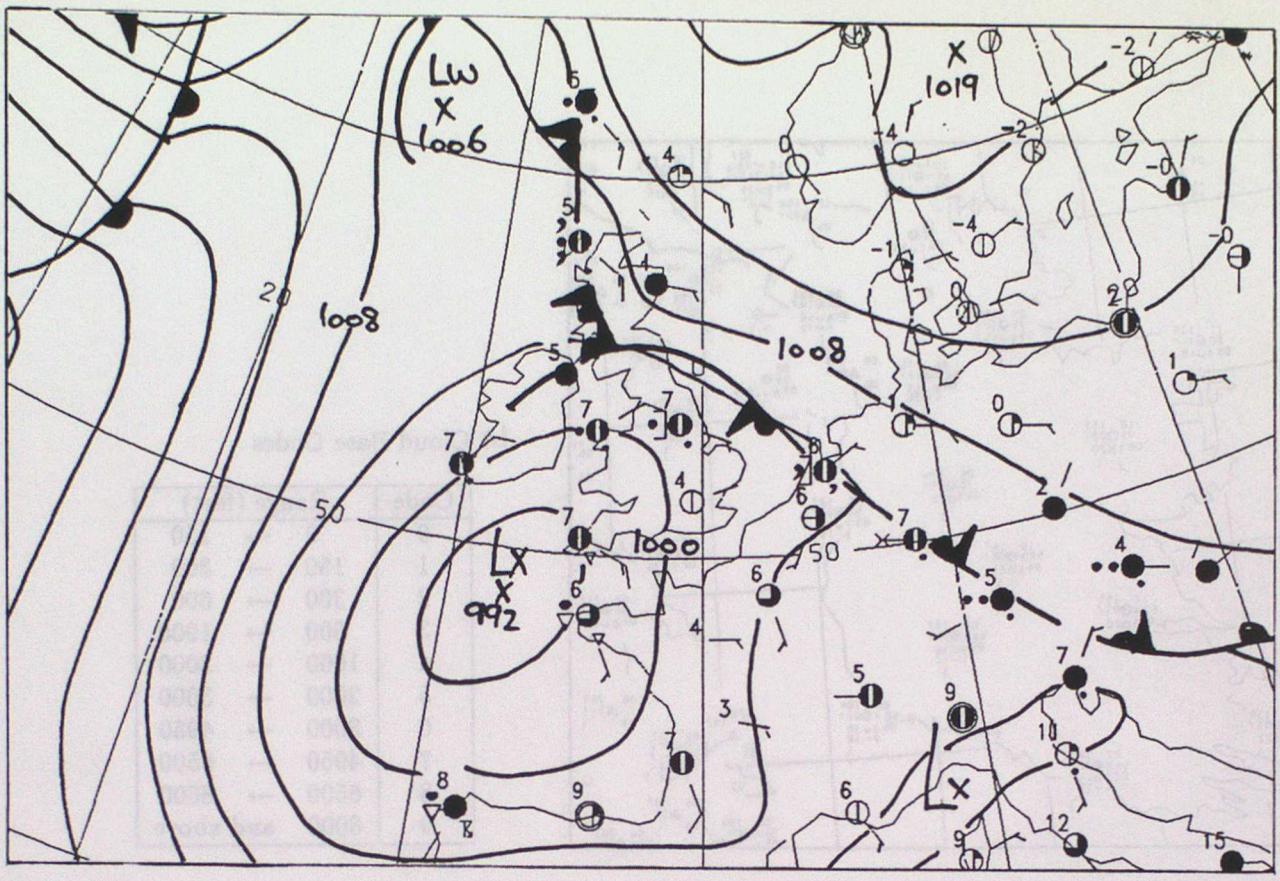


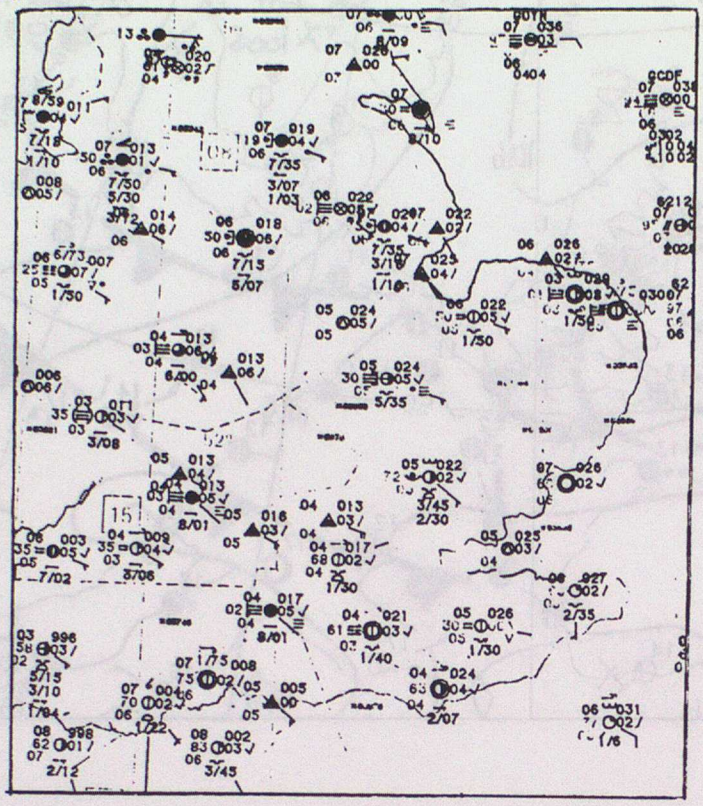

Figure 11: Surface synoptic chart for 6 UTC 12/4/93.

The forecaster in CFO carried out the MOPS. The notes in the CFO MOPS log indicate that the forecaster added cloud over northern France, and reduced the the automatically diagnosed cloud tops from 8000–16000 feet to 4000 feet over much of England and Wales. Cloud was added below the inversion over southern England.

The cloud predictions from the two forecasts are quite similar. Both do badly at predicting the low cloud over England and Wales. Although the southern edge of the cloud sheet, lying from the Isle of Wight through the middle of East Anglia at 6 UTC, is well defined at the start of the forecast, the cloud over northern England is too broken. The forecast cloud dissipates from the north as well as correctly clearing from the south. The result is no cloud in either forecast over England and Wales at T+6. In reality there was cloud over Cornwall, Devon, Wales and all of England north of a line from Bristol to the middle of East Anglia. The temperature and humidity profiles suggest that the OR forecast suffers from a cloud top assignment problem in the MOPS data, as for case 1 (see section 3.2.1). The cloud in the AutoMOPS forecast is much better, although slightly too high. However, the effect is lost in the forecast, as the cloud is lost by both runs.

Some differences in the low cloud are apparent over Ireland. In this area, he cloud structure consisted of at least two distinct layers: a layer of stratocumulus with bases in the range 3000–5000 feet, and patchy stratus with bases between 800–2000 feet, which became more extensive later in the forecast period (figure 10a). In the west of Ireland the cloud was more broken, typically cumulus with bases around 2000–2500 feet. The AutoMOPS forecast has a good representation of the stratocumulus layer, but does not have the lower stratus at the start of the forecast (figure 10c). However, it does develop lower cloud by about T+9, which agrees quite well with the observed cloud. The OR forecast has both the stratus and stratocumulus cloud layer from the start of the forecast, but the amounts of low cloud are too large (figure 10b). It is difficult to assess which is better.

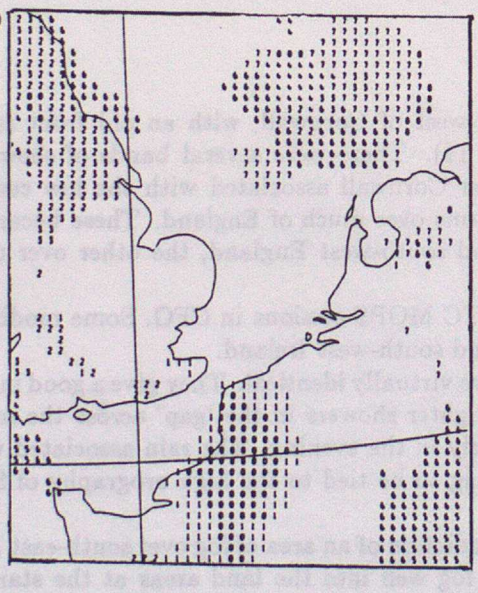
a)



b) Cloud Base Codes

| Code | Range (feet) | | |
|---|---|---|---|
| 0 | 0 | → | 150 |
| 1 | 150 | → | 300 |
| 2 | 300 | → | 600 |
| 3 | 600 | → | 1000 |
| 4 | 1000 | → | 2000 |
| 5 | 2000 | → | 3000 |
| 6 | 3000 | → | 4950 |
| 7 | 4950 | → | 6500 |
| 8 | 6500 | → | 8000 |
| 9 | 8000 | and above | |

c)



d)

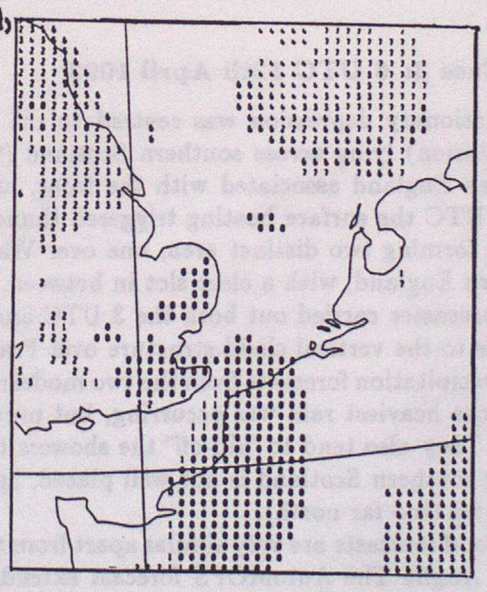


Figure 12: Fog at 12 UTC 12/4/93 a) Surface synoptic observations, b) Mesoscale Model cloud base codes, c) Operational re-run T+6 coded cloud base forecast, d) AutoMOPS T+6 coded cloud base forecast (a base code of 0 indicates fog).

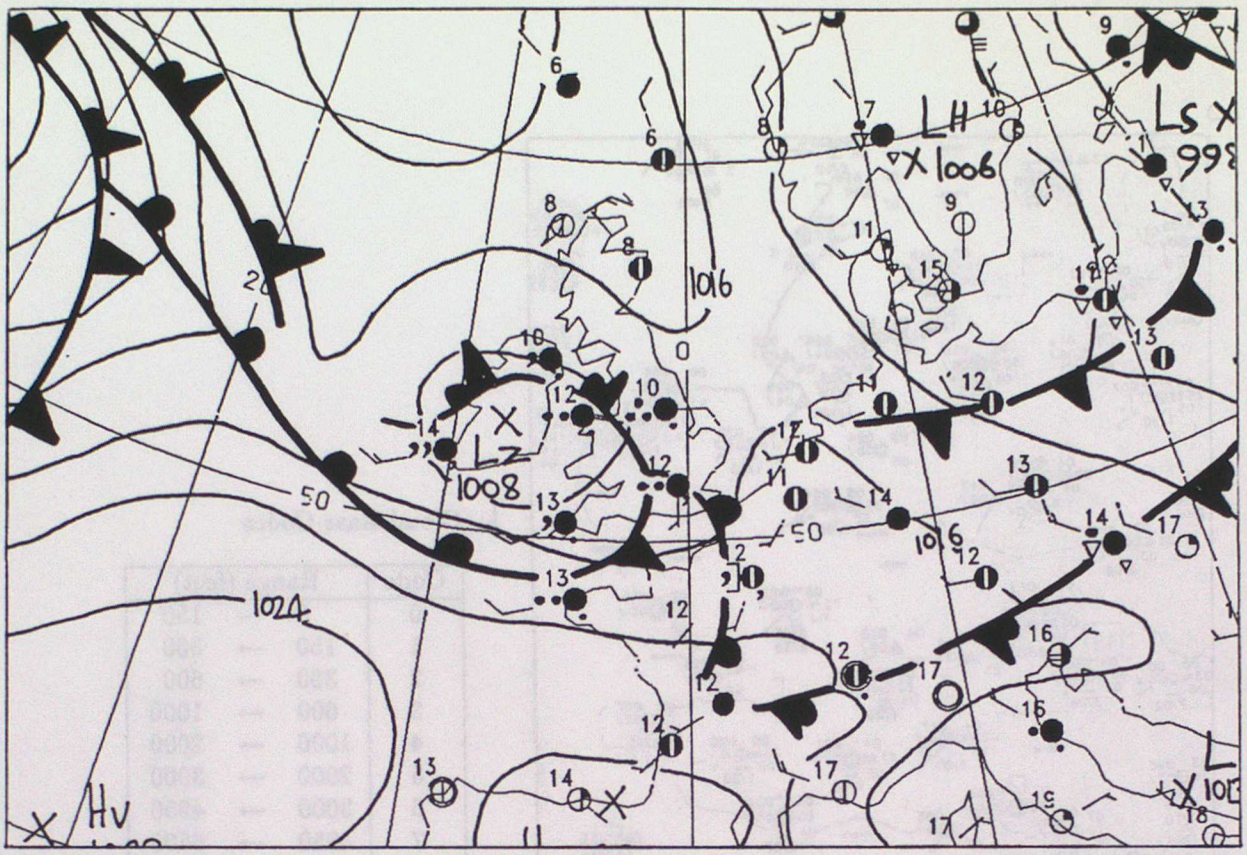



Figure 13: Surface synoptic chart for 6 UTC 14/6/93.

### 3.2.3 Case 3: 6 UTC 12th April 1993

A near-stationary depression was centred to the south-west of Cornwall, with an old front (analysed as an occlusion) lying across southern Scotland (figure 11). There were several bands of showery rain in northern England associated with the front, and over Cornwall associated with the low centre. At about 12 UTC the surface heating triggered thunderstorms over much of England. These became more organized forming two distinct area, one over Wales and south-west England, the other over northern and eastern England, with a clear slot in between.

The forecaster carried out both the 3 UTC and 6 UTC MOPS sessions in CFO. Some modifications were made to the vertical cloud structure over France and south-west Ireland.

The precipitation forecasts from the two model runs are virtually identical. They give a good indication of where the heaviest rain was occurring, but produce lighter showers in the 'gap' across the middle of England. They also tend to 'kill-off' the showers too early in the evening. The rain associated with the front over southern Scotland is not well placed, appearing to be tied to the high orography of Scotland in the model (too far north).

The cloud forecasts are very similar apart from the prediction of an area of fog over south-east England and East Anglia The AutoMOPS forecast extends the fog well into the land areas at the start of the forecast (figure 12d). The OR forecast keeps the fog mainly out to sea, only just infringing on the coast (figure 12c). In reality, fog did develop over much of this area (figure 12a), being most extensive at 7 UTC, but quickly dispersed after that. The AutoMOPS forecast gives better guidance for the occurrence of the fog, but maintains the fog too long.

### 3.2.4 Case 4: 6 UTC 14th June 1993

A small depression which was over Ireland at the start of the forecast period, moved east-south-eastwards across southern England (figure 13). The system exhibited a double banded frontal structure, with some of the heaviest rain associated with the second band.

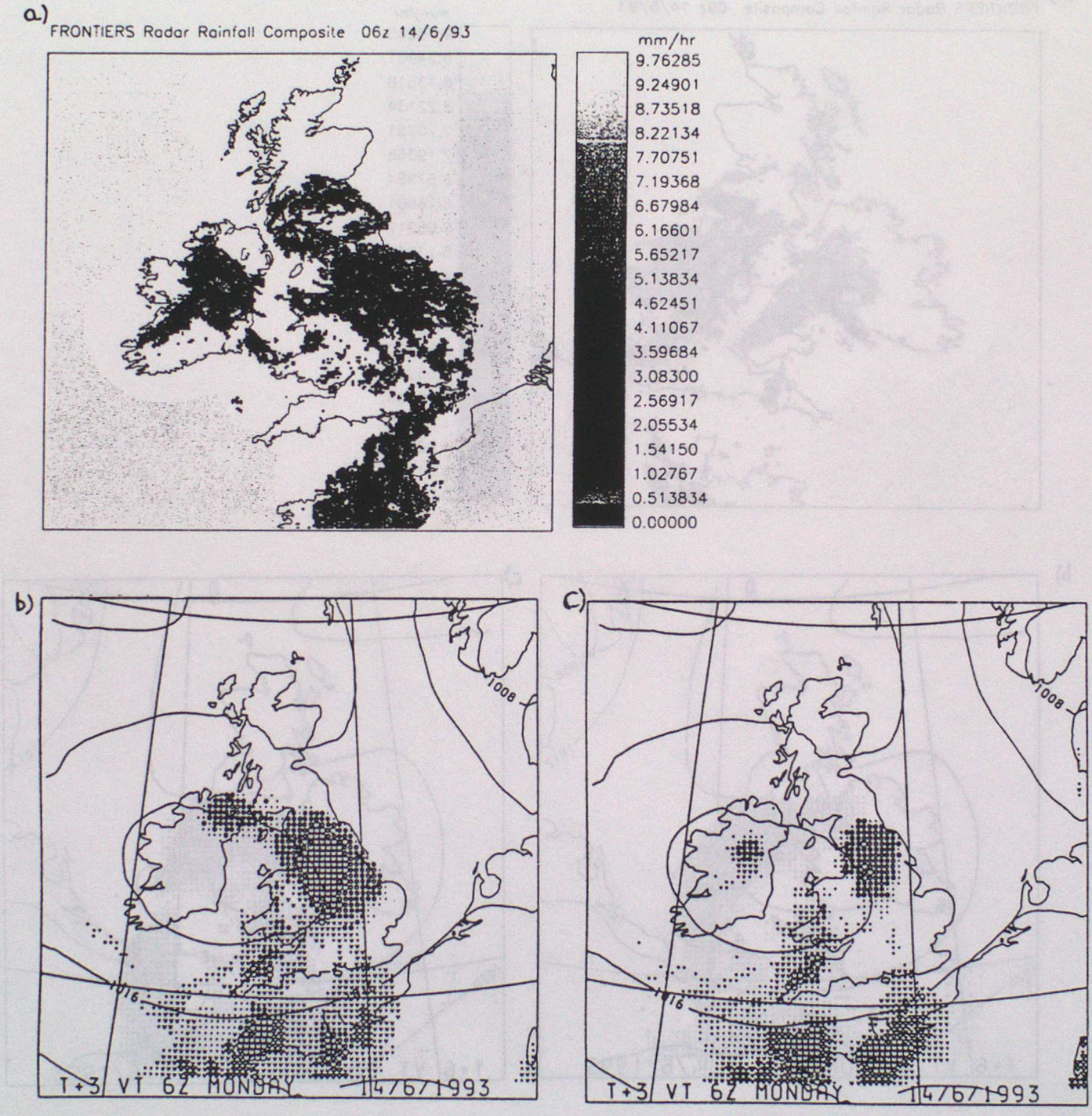



Figure 14: Radar imagery and model valid at 6 UTC 14/6/93 a) FRONTIERS radar image, b) Operational re-run T+0 forecast, c) AutoMOPS T+0 forecast.

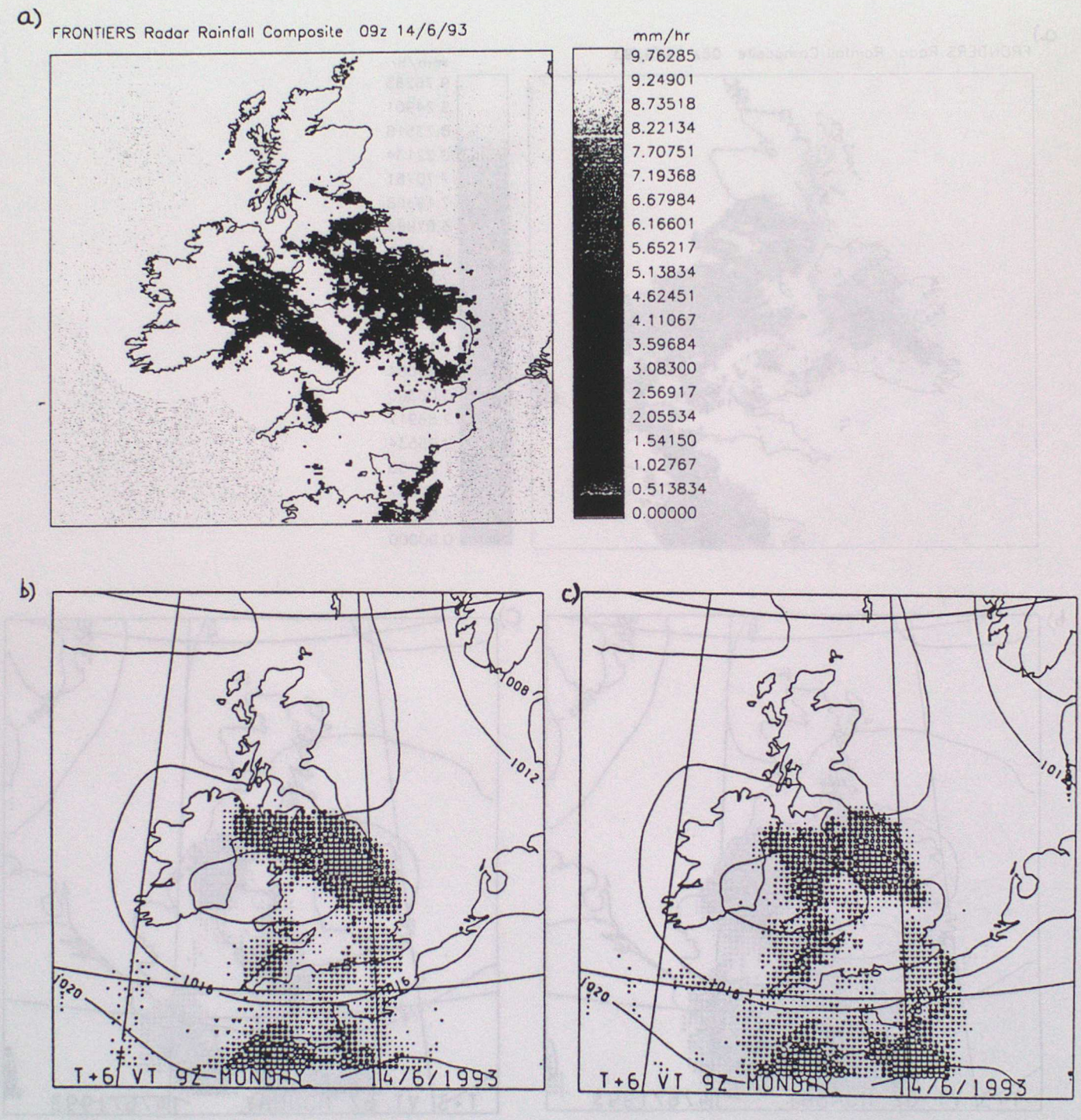



Figure 15: Radar imagery and model valid at 9 UTC 14/6/93 a) FRONTIERS radar image, b) Operational re-run T+3 forecast, c) AutoMOPS T+3 forecast.

No MOPS sessions were carried out in CFO for the operational forecast. Bearing in mind that on average 22% of 6 UTC MOPS sessions are not performed operationally (see section 1), this can still be considered to be within the typical levels of CFO intervention.

At 6 UTC, a wide band of rain covered most of central and northern England, southern Scotland and North Wales, with a separate area of rain over central Ireland, and a further band stretching northwards from France into Kent (figure 14a). The OR forecast (figure 14b) has a good representation of the main band of rain, although it does not have rain far enough north. The AutoMOPS forecast (figure 14c) has too little rain over England—less than the OR forecast. The OR forecast has some rain over northern Ireland, which appears to be an extension of the the main band over England, and is not well placed. The AutoMOPS has a separate area of rain over central Ireland, which is in the right place, but too.

By 9 UTC, the rain band over England had not moved much. However, the area of rain which had been over Ireland had moved over the Irish Sea, and some very heavy rain was just beginning to push into Wales (figure 15a). At this time, the AutoMOPS forecast (T+3) (figure 15c) is considerably better than the OR forecast (figure 15b). It has developed the area of precipitation over Ireland, bringing heavy rain into Wales. This is absent from the OR forecast. The description of the main band of rain is similar in the two forecasts.

Beyond this time, the AutoMOPS forecast merges the two areas of rain, whereas in reality the double-banded structure was maintained. However, the AutoMOPS forecast is still giving a better rainfall prediction than the OR forecast at T+6. Beyond T+6, the two forecasts are very similar, both tending to keep too much rain over England.

In general, the cloud cover distribution through the forecast period reflects in the precipitation distribution. For example, the OR forecast has better (more extensive) cloud cover over East Anglia, and the AutoMOPS has better (more) cloud over Ireland. Surprisingly, the AutoMOPS forecast has the northern cloud edge further north than the OR forecast, which is better, although both are deficient in cloud over Scotland.

### 3.2.5 Temperatures

In all the forecasts it is observed—as would be expected—that the temperatures are principally controlled by the presence (or absence) of cloud and/or precipitation. Where the forecast has too little cloud, before sunrise, the model cools too much, introducing a negative mean temperature bias, after sunrise it warms too much introducing a positive temperature bias. No systematic differences between the forecasts are apparent.

## 4 Reliability Studies

Apart from the four forecasts documented in this paper, no further reliability studies were carried out specifically to assess the frequency of significant errors. However, a separate study, which was carried out to assess the impact of running four model runs per day, linked by a truly continuous data assimilation cycle, did use AutoMOPS [3]. The study covered three distinct periods, with four or five full model runs in each, all of which were assessed. Including the cases studies discussed in this paper, this brings the total number of verified forecasts which have been run using AutoMOPS data to eighteen. None of these forecasts have shown significant errors as a result of the use of AutoMOPS. This suggests that the AutoMOPS is not prone to gross error. Additionally, it satisfies the reliability quality requirement stated in section 1, that significant errors should occur in less than 1-in-10 forecasts due to the replacement of the interactive with the automatic cloud analysis.

## 5 Summary and Conclusion

An automated version of the Moisture Observation Pre-processing System (AutoMOPS) has been developed. It includes an improved algorithm for the detection of satellite cloud and a new method of cloud top height assignment. Forecasts run using AutoMOPS data were compared with re-runs of the current Mesoscale Model, but using the operational (CFO-generated) MOPS data (to reduce the effect of subsequent model changes); all forecasts used Unified Model version 3.1. The AutoMOPS forecasts did not use the MOPS data at level 1 (in preparation for the introduction of dew point temperature data).

The comparisons were carried out for four cases (two low cloud dominated, two precipitation dominated), which represented a typical cross-section of CFO intervention.

Overall, the use of AutoMOPS produced forecasts of a slightly better quality than the operational re-runs. Objective verification demonstrated significant improvements in the cloud cover and cloud base predictions. Screen temperatures were of a similar quality.

Subjective study of the cases revealed a better maintenance of low cloud in the AutoMOPS forecasts. This is thought to be due to the better representation of the cloud sheets as result of the use of the new cloud top height assignment scheme. The use of this scheme is probably also responsible for large reductions in the cloud base height errors at the start of the forecast. One of the precipitation case predictions was markedly improved at the start of the forecast through the use of AutoMOPS data, although this was probably due to the lack of operational MOPS data (no CFO intervention was performed); the impact was short-lived.

The operational re-run forecasts showed a tendency to produce more cloud in the bottom few levels of the model, probably due to the non-use of the MOPS data at level 1 in the AutoMOPS forecasts. However, the AutoMOPS forecast did produce more fog in one of the cases. For both of the above observations, it is difficult to verify which of the forecast runs was better; each has its good and bad points. There was little effect on other forecast variables.

Consideration of these and other cases used in a separate study, suggests that the AutoMOPS is not prone to gross error.

The adoption of AutoMOPS will provide a saving of 95 minutes per day of forecaster time. It is a prerequisite for the introduction of four operational Mesoscale Model runs per day and the introduction of a truly continuous data assimilation scheme. It will allow MOPS to be incorporated into Nimrod. Being a smaller piece of software, with better (internal and external) documentation, AutoMOPS offers easier code management. Because it is fully automatic, it facilities easy assessment and study of the whole and component parts of the system. In view of these advantages, and the slight improvements to the forecasts obtained through its use in the case studies, it is recommended that AutoMOPS is adopted operationally.

## References


[1] Ballard, S. P., R. Robinson, R. T. H. Barnes, S. Jackson and S. Woltering, 1993: Development and Performance of the New Mesoscale Model. *Met. Office FR-Div. Tech. Rep.*, **No. 40**.

[2] Ballard, S. P. and B. Macpherson, 1993: Operational Performance of Mesoscale and LAM Models in Prediction of Stratocumulus. *Met. Office FR-Div. Tech. Rep.*, **No. 56**.

[3] Clark, P. A., R. Robinson, A. J. Maycock, S. Woltering, B. Macpherson, R. N. B. Smith, S. Jackson and B. J. Wright, 1993: The Performance of Phase 1 and Phase 2 Changes to the Mesoscale Model. *Met. Office FR-Div. Tech. Rep. (forthcoming).*

[4] Cullen, M. J. P., 1991: The Unified Forecast/Climate Model. *Met. Office S-Div. Sci. Pap.*, **No. 8**.

[5] Golding, B. W., 1990: The Meteorological Office Mesoscale Model. *Met. Mag.*, **119**, 81–96.

[6] Hand, W. H., 1993: A Method of Improving the of Cloud Top Height for the New Mesoscale Model. *Met. Office FR-Div. Tech. Rep.*, **No. 53**.

[7] Lorenc, A. C., R. S. Bell and B. Macpherson, 1991: The Meteorological Office Analysis Correction Scheme. *Q. J. R. Met. Soc.*, **117**, 59–89.

[8] Purser, R. J., and R. McQuigg, 1982: A Successive Correction Analysis Scheme Using Recursive Numerical Filters. *Met. Office, Met O 11 Tech. Note*, **No. 154**.

[9] Schmetz, J., 1986: An Atmospheric-Correction Scheme for Operational Application to Meteosat Infrared Measurements. *E. S. A. Journal*, **10**, 145-159.

[10] Smith, R. N. B., D. Gregory and C. Wilson, 1993: Calculation of Saturated Specific Humidity and Large Scale Cloud. *Met. Office, U. M. Doc. Pap.*, **No. 29**.

[11] Wright, B. J., 1993: The Moisture Observation Pre-processing System (MOPS). *Met. Office, FR-Div. Tech. Rep.*, **No. 38**.